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Impact of Mineral Fertilizer Integration with Farmyard Manure on Crop Yield, Nutrient Use Efficiency, and Soil Fertility in a Long-Term Trial

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1. Introduction

Plant nutrient should be well managed to increase productivity of crop production with responsibility to protect environment. The major purposes of plant nutrient management include: (1) to budget and supply nutrients for crop production; (2) to properly utilize manure or organic byproducts; (3) to minimize agricultural nonpoint source pollution of surface and ground water resources; (4) to protect air quality by reducing nitrogen loss; and (5) to maintain or improve the physical, chemical, and biological condition of soil (NRCS and NHCP, 2006). Availability of sufficient amount of nutrients at the right place and time is an essential factor to maximize crop yield per area. Plant nutrient management is defined as application of right form, quantity, and ratios of nutrient at a right location and growth stages of crop to increase yield per area with a minimum nutrient loss. It is described as fertilizer best management practices, integrated plant nutrient management, code of best agricultural practices, site-specific nutrient management, and other similar expressions (Roberts, 2010).

Nutrient recycling by application of organic fertilizer is needed to replace nutrient removed by crop yield from fields in order to restore crop production potential of a soil. But application of organic fertilizer alone insufficiently increases crop yield per area because nutrient content of organic fertilizer is unbalanced and if it is applied in a large quantity to balance nutrient supply the loss will increase. Therefore integrated plant nutrient management (IPNM) can minimize the problem. IPNM is application of mineral fertilizer in combination with locally available organic fertilizer to maintain soil fertility and to balance nutrient supply in order to increase crop yield per area. It is one of the best practices of plant nutrient management to take into consideration mineral fertilizer integration with organic sources of the plant nutrients to optimize social, economic, and environmental benefits of crop production. The main objectives of the IPNM are: (i) to maintain or enhance soil productivity, (ii) to improve stock of plant nutrient in the soil; (iii) to limit nutrient loss to the environment by improvement of nutrient use efficiency (FAO, 1998).

One of the most important challenges to continuously satisfy growing food demand is maximization of crop production on limited areas of agricultural land. Sustainable production of crop requires adequate supply of plant-available nutrients to support crop growth and that the nutrients removed in the harvested material or in the exported product of livestock systems must be replaced so that soil fertility is not depleted over time: and at the same time, excess nutrient accumulation must be avoided to reduce the risk of nutrients moving out of the root zone to the air and water (Aulakh and Grant, 2008). Management of plant nutrient can potentially address the challenge through soil fertility improvement and reduction of nutrient loss. Soil fertility is the capacity of a soil to retain, cycle and supply essential nutrients for plant growth over extended periods of time (Alley and Vanlauwe, 2009). Nutrient and organic matter content of the soil determines status of its fertility. Soil organic matter is an important index of soil fertility (Rahman and Parkinson, 2007). It improves soil fertility with the following functions: source of inorganic nutrient for crops and microbial biomass, exchange of ions, chelating agent and buffer, aggregating soil particles, support root development, and water conservation (Allison, 1973). In addition, it reduces level of atmospheric CO2 that contributes positively to climate change (USDA and NRCS, 2003).

The concept of IPNM primarily optimizes the use of nutrients in organic fertilizer to maximize crop yield per area and to improve nutrient use efficiency (NUE) synergistically. Improvement of NUE implies reduction of nutrient losses so that it indicates environmental impact of nutrient management. NUE in agriculture can be considered from three major perspectives: (i) as 'agronomic efficiency' that concerns optimization of nutrient uptake by crop; (ii) as 'economic efficiency' that implies improvement of nutrient input increases profitability of crop production; and (iii) as 'environmental efficiency', i.e. minimization of losses of nutrient to the environment (Robert, 2005). There are different methods to express NUE. This study uses the 'difference method', i.e. total nutrient removal of fertilized crop minus total nutrient removal of unfertilized crop per fertilizer rate (Varvel and Peterson, 1990). It is appropriate to use the method in the long-term trials because nutrient is residually accumulated each year.

This paper analyzes a long-term agronomic field trial comparing different schemes of integration of mineral fertilizer with Farm Yard Manure (FYM) in the production of potato, rye, and oat from 1958 – 2008. The objective of the trial is to measure the effects of IPNM on economic, social, and environmental dimensions of crop production sustainability. Moreover it investigates whether organic or mineral fertilizer alone can sustain nutrient demand of crop at the right balance to achieve the highest yield. It evaluates benefits of supplementing organic with mineral fertilizer and balanced mineral fertilizer application in crop production compared to application of organic fertilizer alone. Nutrient management affects ability to maximize crop yield per area, which is a primary factor to produce sufficiently high quality food, feed, and fiber in economically viable systems of production. There are three major components of plant nutrient managements, which are known as nutrient recycling or organic plant nutrient management (OPNM), IPNM, and balanced plant nutrient management (BPNM). In this study the three components of plant nutrient managements are considered as FYM alone (OPNM), FYM + mineral fertilizer (IPNM), and mineral N+PK+Mg fertilizers alone (BPNM). The analysis deals with the evaluation of social and economic (crop yield), environmental (NUE), and soil fertility (organic matter and nutrient index) benefits of the IPNM and the BPNM compared to the OPNM.

2. Material and methods

2.1 Location and history

The Hanninghof long-term trial is located near Duelmen in Western Germany. The experiment started in 1958 with potato cultivation. The potato was followed by winter rye in 1959 and oat in1960. Since then each crop was cultivated 17 times in rotation. Long-term experiments (LTE) are classified as: classical (longer than 50 years); medium length (20 – 50 years old); and young (less than 20 years) long-term trials (Steiner and Herdt, 1993). The Hanninghof long-term trial completed its medium phase in year 2008 and it entered its classical stage in 2009. It is listed along the most prominent classical LTE in the world.

2.2 Soil and climate

The soil is a sandy with the following initial soil parameters: carbon total 1%, N total 0.1%, pH 6, P2O5 12 mg (100 g) $^{-1}$ and K2O 5 mg (100 g) $^{-1}$. Annual average rain fall (1961 – 2008) was 885 mm and average air temperature (1962 – 2008) was 10 °C. Spring and summer averages were 201mm and 243 mm rainfall and 9 °C and 18°C air temperature, respectively.

2.3 Layout

The trial is a two factorial experiment with the factors mineral fertilizer with and without FYM. The layout is a split-plot design with a randomized complete block design. The cultivated area of the trial is 0.3ha (72 × 42m). The field is split into two parts, one receiving FYM every three years and one receiving no additional organic material. Each of the two parts is subdivided into 32 plots i.e. 64 plots in total. The gross area of each plot is 4.5×10.5m with a harvested net area of 4×10m.

2.4 Treatment

A total of 16 treatments were established as shown in Table 1. Each treatment is replicated four times and randomly assigned to 64 plots. In 1960, a treatment with N only (#8 and #16) was introduced. Since the trial was already ongoing for two years a new control for treatments # 8 and # 16 was established. Because they were not different from the old control treatments (#2 and #10) the new control treatments (#7 and #15) are omitted from analysis of the result (Table1).

Mineral fertilizer with FYM		Mineral fertilizer without FYM	
#	Treatments	#	Treatments
1	FYM + N + P	9	N + P
2	FYM	10	Control (without mineral fertilizers)
3	FYM + N + K	11	N + K
4	FYM + N + P + K	12	N + P + K
5	FYM + P + K	13	P + K
6	FYM + N + P + K + Mg	14	N + P + K + Mg
7	FYM	15	Control (without mineral fertilizers)
8	FYM + N	16	N

Table 1. Description of treatments.

Mineral fertilizer N, P, K, and Mg application rates for each crop are given in Table 2. The mineral fertilizer rates were the same for the two parts of the trial with and without FYM.

Crop	Years	Mineral fertilizer application rate (kg ha $^{-1}$)			
		N	P2O5	K2O	MgO
Potatoes	Initial 1958	100	90	160	50
	Since1979	140	90	160	50
Winter rye	Initial 1959	60	90	120	50
	Since 1980	140	90	120	50
Oat	Initial 1960	100	90	120	50

Table 2. Mineral fertilizer application rate for potatoes, winter rye, and oat from 1958 – 2008.

P, K, and Mg mineral fertilizer were applied once at planting for all crops. N mineral fertilizer was applied once at planting for potatoes but split applied for winter rye and oat (Table 3).

Crop	Years	N application according to growth stages (kg ha $^{-1}$)				
		Planting	Early vegetative	2 weeks later	Stem elongation (BBCH 30/31)	Booting (BBCH 49)
Winter rye	Initial 1959	-	60	-	40	40
	Since 1995	-	30	30	40	40
Oat	Initial 1960	60	-	-	-	40

Table 3. Mineral N fertilizer application time for winter rye and oat from 1959 – 2008.

FYM was applied as pig manure at a rate of 25 t ha $^{-1}$ once every three years in spring 10 days before potato planting. The 25 t ha $^{-1}$ FYM was applied once in rotation to supply nutrient requirement of potato, winter rye, and oat production. It was a typical manure application rate in 1958. Nutrient content of FYM is given in Table 4 (YARA and KTBL, 2005).

Unit	Amount of N, P, K, and Mg in pig manure			
	N total	P2O5	K2O	MgO
kg t $^{-1}$	7	6.7	7.2	2.2
kg ha $^{-1}$	175	167.5	180	55

Table 4. Nutrient contents of 25 t ha $^{-1}$ pig manure (FYM).

Since 1958, lime (CaO) was applied to the whole field at a rate of 1000kg ha $^{-1}$ every three years to stabilize soil pH.

2.5 Measurements

Crop fresh and dry matter yields were recorded. N, P, and K concentrations of tuber, grain, and straw were analyzed. The straw of winter rye and oat were removed from the field.

Soil organic matter content was measured as C total and N total at depth of 0 – 30 centimetres (cm).

Soil P2O5, K2O, and pH levels were measured at 0 – 30 cm.

Mineralized N as $NH4^{+}$ & $NO3^{-2}$ and mineralized sulphur as $SO4^{-2}$ were measured at three depths: 0 – 30 cm, 30 – 60 cm, and 60 – 90 cm.

2.6 Statistical analysis and calculations

The differences between average dry matter yields of treatments were analyzed statistically. During 1958 – 2008 each crop was grown 17 times in rotation. The average yield of each crop was calculated as an average of 17 years for each of the 4 replicates of a treatment in which each crop was grown. The average replicates were considered in comparison of means of potato tuber yield, winter rye grain yield, and oat grain yield.

The difference method was used to calculate nutrient use efficiencies. NUE (%) = Nutrient removal with fertilized crop minus nutrient removal with unfertilized crop divided by fertilizer rate × 100 (Varvel and Peterson, 1990). The N fertilizer use efficiency, for example, was calculated as the total N removal of the crop (tuber, grain, and straw) yield fertilized with N minus total N removal of crop yield without fertilizer (control treatment) divided by total N fertilizer rate times 100. The calculation was done in a similar way for P and K fertilizer use efficiencies.

Soil fertility levels were indicated by relative increase of C-total, and P2O5 and K2O content.

3. Results

This paper mainly focuses on the results of a combination of FYM with mineral fertilizers as an example of the IPNM in comparison to the results of application of FYM alone as an example of the OPNM.

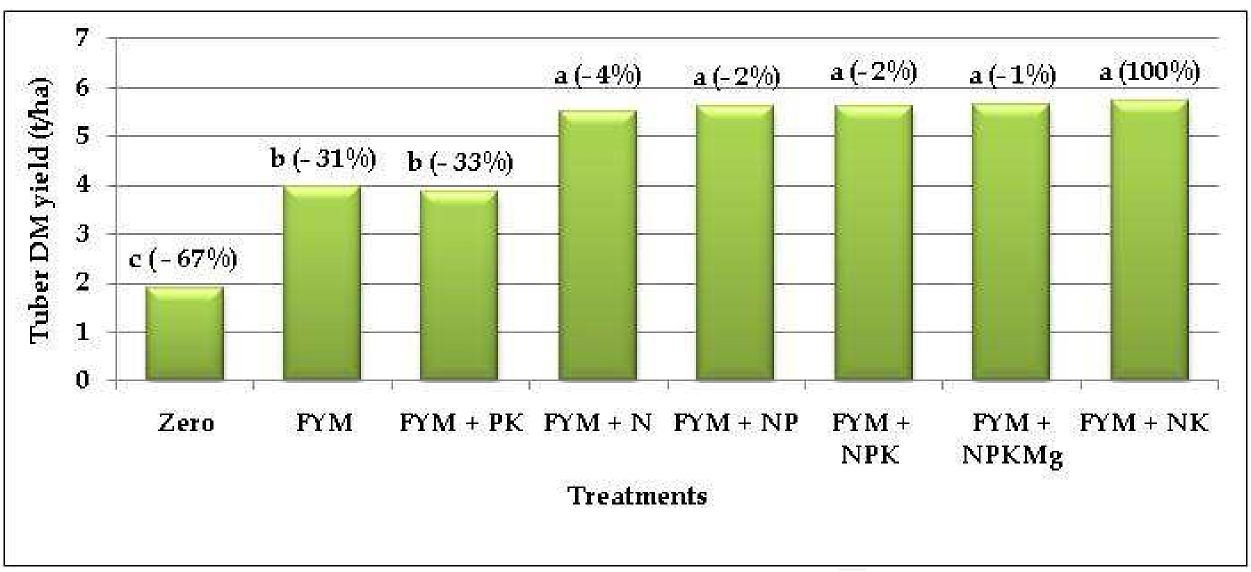

Fig. 1. Average potato yield (1958 –2006, n=17) at different combination of mineral fertilizer with FYM.

3.1 Effects of application of FYM alone, the combination of FYM with mineral fertilizer, and mineral fertilizer alone on crop dry matter (DM) yield

3.1.1 Average tuber yield of potato

Application of FYM plus mineral fertilizer was increased potato yield. The highest yield of potato tuber was measured at 5.74 t ha $^{-1}$ in the treatment of the combination of FYM with mineral NK fertilizer. The average yield of 5.74 t ha $^{-1}$ is quite low and can be explained by the low yielding variety of potato at early decades of the trial and low water supply because of the sandy texture of the soil at the site. Integration of mineral P fertilizer with FYM did not achieve the highest yield because potato tuber yield is more responsive to K than P fertilizer. Application of FYM (i.e. organic fertilizer) alone decreased potato yield by 31% in comparison to integration of mineral NK fertilizer with FYM (Figure 1). Application of FYM alone and omitting application of mineral N+Mg, PK+Mg, and Mg fertilizers reduced potato yield by 15%, 57%, 41%, and 12%, respectively in comparison to the application of N+PK+Mg fertilizers without FYM (Figure 4). Balanced mineral fertilizer application (i.e. the N+PK+Mg treatment without FYM) achieved more additional yield than application of FYM alone even though less amount of N, P, K, & Mg were applied as mineral fertilizer in comparison to nutrient content of FYM at the year of potato cultivation of each of the rotations (Table 4).

3.1.2 Average grain yield of winter rye

The crop yield was increased with application of FYM plus mineral fertilizer. Application of mineral NP fertilizer with FYM achieved the highest average grain yield of 5.1 t ha $^{-1}$ but application of FYM alone reduced crop yield by 56% in comparison to the highest yield (Figure 2). Organic fertilizer (FYM treatment) alone and omitting application of mineral N+Mg, PK+Mg, and Mg fertilizers reduced winter rye yield by 51%, 61%, 9%, and 3%, respectively compared to the yield of the treatment with N+PK+Mg (balanced mineral fertilizer) application (Figure 4). Effect of organic fertilizer (FYM) on winter rye yield was reduced, because most of the nutrient in the FYM was consumed by cultivation of potato before winter rye in a rotation (Figure 4).

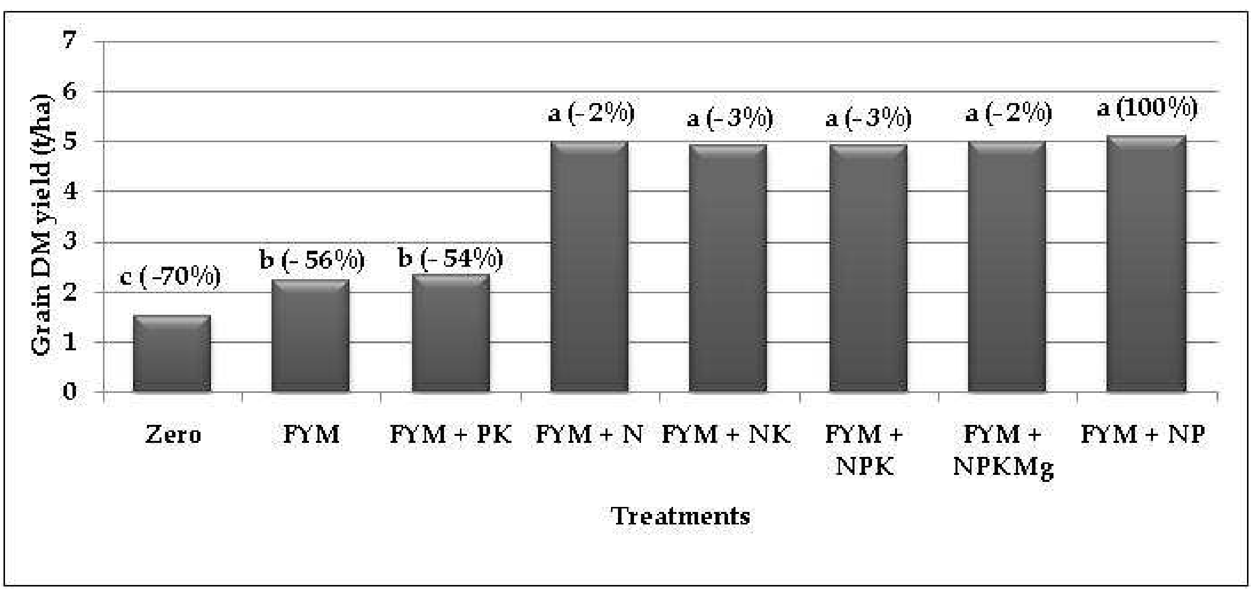

Fig. 2. Average winter rye yield (1959 –2007, n=17) at different combination of mineral fertilizer with FYM.

3.1.3 Average grain yield of oat

The highest average yield of oat grain was measured at 3.97 t ha $^{-1}$ in the combination of mineral NP with organic fertilizer. With application of FYM alone the yield was reduced by

56% compared to the highest yield, but the yield was increased with application of FYM plus mineral fertilizer (Figure 3). Organic fertilizer (FYM) alone and omitting application of mineral N+Mg, PK+Mg, and Mg fertilizers reduced oat yield by 52%, 60%, 28%, and 5%, respectively in comparison to the balanced mineral fertilizer application (Figure 4). Unbalanced mineral fertilizer application is the result of either omitting, insufficient, or over application of one or more nutrient. Omitting application of mineral N, PK, and Mg fertilizers reduced crop yield, because specific function of a nutrient cannot be replaced with specific functions of other nutrients.

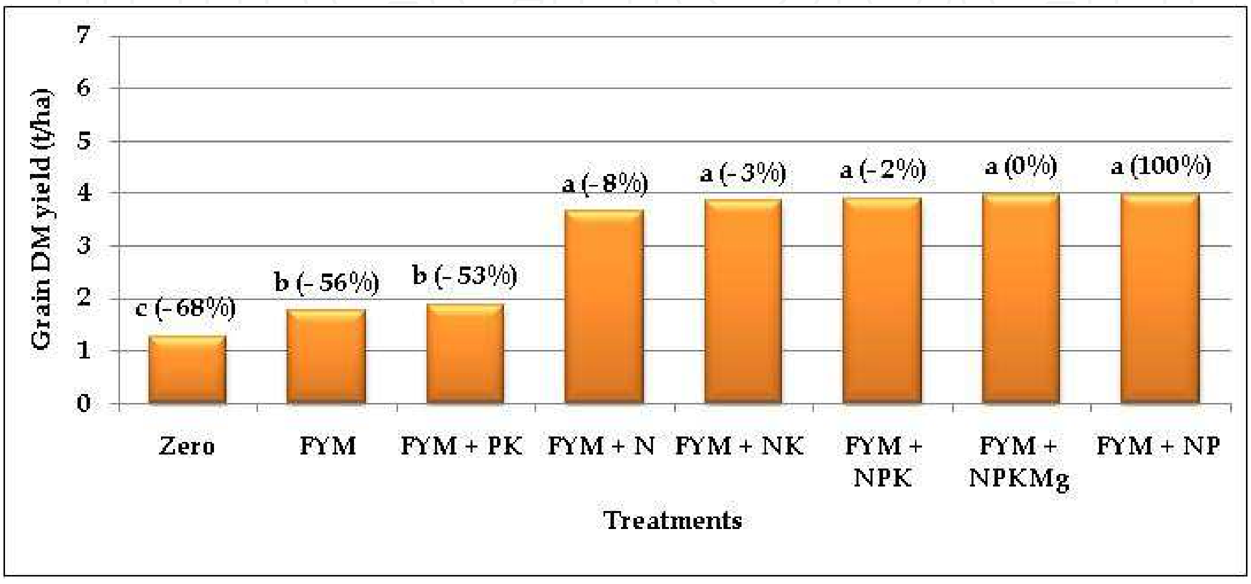

Fig. 3. Average oat yield (1960 –2008, n=17) at different combination of mineral fertilizer with FYM.

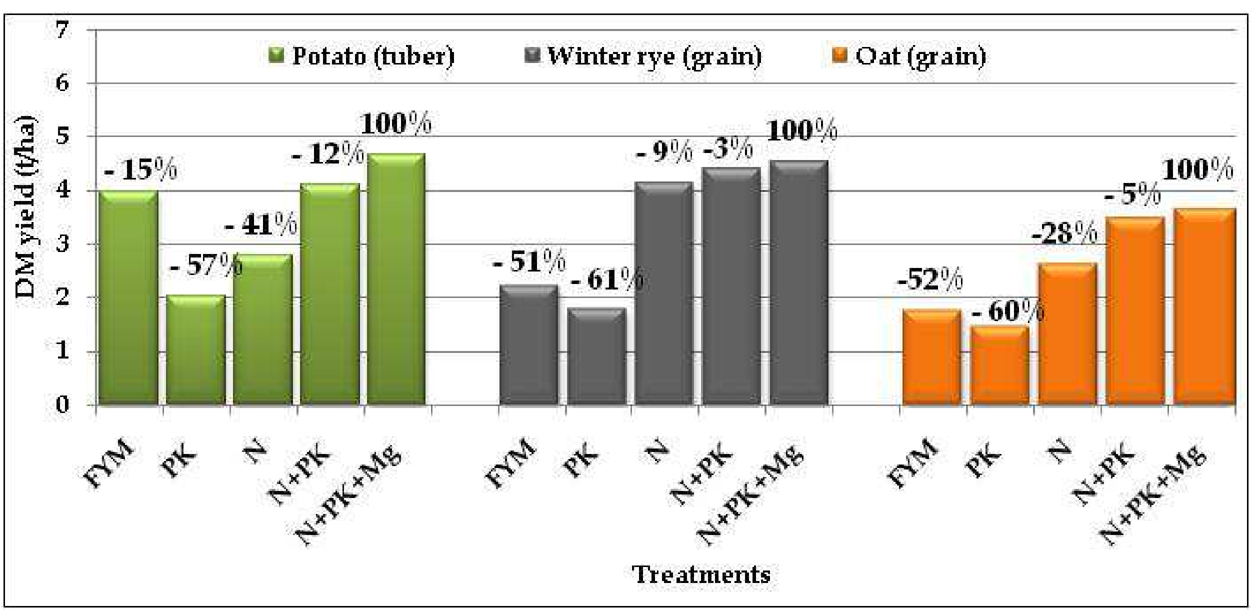

Fig. 4. Average crop yield (1958 –2008) at application of FYM alone and mineral fertilizer without FYM.

3.2 Effects of application of FYM, combination of FYM with mineral fertilizer, and mineral fertilizer alone on nutrient use efficiency of crop

The effect of nutrient management on N, P, and K fertilizers use efficiency of crops during 50 years of the experiment is explained as follows.

3.2.1 The N fertilizer use efficiency (NFUE)

The combination of mineral N and P fertilizers with organic fertilizer (FYM) achieved the highest NFUE in comparison to all the treatments with FYM (Table 5). Application of FYM alone decreased NFUE of crop by 27% in comparison to the highest NFUE (Table 5). The combination of mineral with organic fertilizer resulted in a higher NFUE than application of FYM alone. Application of FYM alone and omitting application of mineral PK+Mg or Mg fertilizer reduced NFUE in comparison to the balanced mineral fertilizer application (Figure 5). Neither application of organic fertilizer (FYM) alone nor unbalanced mineral fertilizer application combines benefits of high yield and improvement of NFUE. Improvement of NFUE is required to minimize risk of environmental degradation, because increase of recovery of N by high yield of crop is responsible to reduce loss of N. High crop yield and improvement of NFUE are achieved with the approaches of IPNM and balanced mineral fertilizer application (i.e. the BPNM).

Treatments	N, P, and K fertilizers use efficiency					
	NFUE (%)	Relative to the highest	PFUE (%)	Relative to the highest	KFUE (%)	Relative to the highest
FYM	26.5	-27%	21.7	-63%	54.3	-57%
FYM+PK	29.6	-19%	9.5	-84%	20.5	-84%
FYM+N	33.8	-7%	54.4	-6%	112.1	-12%
FYM+NPKMg	34.8	- 4%	23.8	-59%	48.7	-62%
FYM+NK	35.5	- 3%	57.9	100%	47.8	-62%
FYM+NPK	35.7	- 2%	23.5	-59%	48.8	-62%
FYM+NP	36.4	100%	23.9	-59%	126.9	100%

Table 5. Nutrient use efficiency of crop.

3.2.2 The P Fertilizer Use Efficiency (PFUE)

Application of FYM without mineral fertilizer reduced PFUE of crop by 63% in comparison to the highest PFUE (Table 5). The PFUE of crop was increased in integration of mineral N or NK fertilizers with FYM (Table 5). The highest PFUE was achieved with application of FYM plus mineral NK fertilizer, because nutrient supply for crop demand is balanced. Application of organic fertilizer (FYM) alone and omitting application of mineral N+Mg or Mg fertilizer reduced PFUE in comparison to the balanced mineral fertilizer application (Figure 5). The PFUE of crops in integration of mineral PK with FYM and application of mineral PK without FYM is very low, because mineral P and K fertilizers application without mineral N fertilizer achieved very low yield and poor recoveries of P in tuber, grain, and straw of crops. Yield and the PFUE of crops were increased with the approaches of IPNM and balanced mineral fertilizer application (i.e. the BPNM).

3.2.3 The K fertilizer use efficiency (KFUE)

The combination of mineral N and P fertilizers with organic fertilizer (FYM) resulted the highest KFUE of crop (Table 5). Application of organic fertilizer alone decreased KFUE of crop by 57% in comparison to the highest KFUE (Table 5). Integration of mineral N and NP fertilizers with organic fertilizer increased KFUE of crops in comparison to application of organic fertilizer alone, because it balances nutrient need of crops. Application of mineral NPK and NPK+Mg without FYM did not achieve higher KFUE than application of organic fertilizer alone, because the quantity of K fertilizer applied as mineral was 122% higher than the amount of K applied as FYM alone at each of the complete rotation (Tables 2 and 4). Integration of mineral NP fertilizer with FYM combines the advantages of the highest crop yield and improvement of the KFUE.

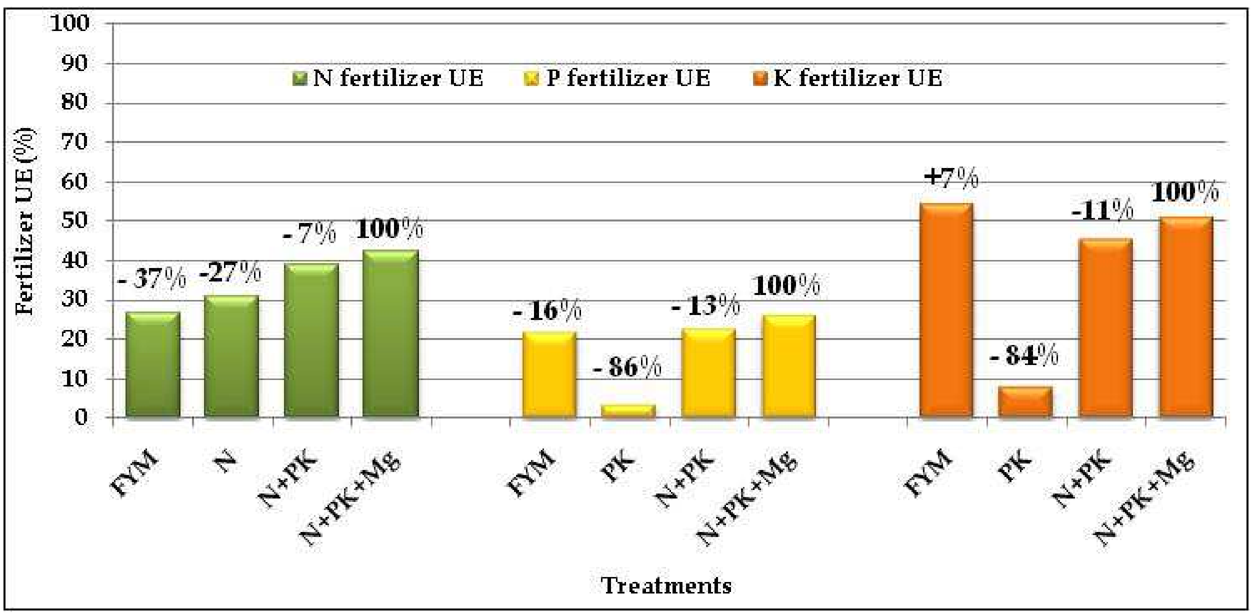

Fig. 5. N, P, and K fertilizers use efficiency of all crops and years.

3.3 Effects of application of FYM alone, the combination of FYM with mineral fertilizer, and mineral fertilizer alone on soil fertility

The effects of application of organic fertilizer (FYM) alone, integration of mineral with organic fertilizer, and balanced mineral fertilizer application on soil fertility during 50 years of the experiment are measured with the levels of soil organic matter content and the development of the P, and K content of the soil. Organic matter and nutrient content are considered as the major indicators of soil fertility.

3.3.1 Level of soil C total

The soil organic matter content was measured as soil C total. Organic matter improves soil fertility through its positive impact on chemical, physical, and biological properties of a soil. In general the level of soil C total is low because crop residues (straw of winter rye and oat) have been removed from the field. Even though the crop residues were removed from the field a significant amount of carbon has been accumulated by root biomass. The level of C total in top soil was increased with the application of farm yard manure (FYM) plus mineral fertilizer and the balanced mineral fertilizer application (the N+PK+Mg treatment).

However organic matter content of the soil was depleted by application of organic fertilizer alone (the FYM treatment) and by unbalanced application of mineral fertilizer (the PK treatment without FYM).The highest accumulation of C total was achieved with application of FYM plus mineral NP fertilizer (Table 6). Integration of mineral N and P fertilizers with FYM resulted in an increase of the soil organic matter content and in addition to this benefit it achieved the highest yield and nutrient use efficiency in comparison to application of FYM without mineral fertilizer.

3.3.2 Level of soil P2O5

The soil P2O5 level indicates the potential of a soil to supply P to a crop. The soil P index in Germany is classified as 'very low' (< 5), 'low' (6 – 9), 'medium' (10 – 20), 'high' (21 – 34), and 'very high' (> 35) mg P2O5 per 100 g soil at 0 – 30 cm depth (YARA and KTBL, 2005). Integration of mineral fertilizers with FYM; and the application of mineral PK and N+PK+Mg fertilizer without FYM increased the status of soil P from medium to the `high` index (Table 7). Application of organic fertilizer (FYM) without mineral fertilizer kept soil P index at the 'medium' level.

The soil P content was depleted from medium to the `low` index by application of mineral N fertilizer without FYM (Table 7). It was depleted by unbalanced mineral fertilizer application (mineral N fertilizer without FYM), because P has been removed through tuber, grain, and straw yields of crops without replacement. Integration of mineral NP fertilizer with FYM and balanced mineral fertilizer application increased soil P content in addition to the high yield of crop, better nutrient use efficiency, and improvement of soil organic matter content in comparison to the organic fertilizer alone and unbalanced mineral fertilizer application.

3.3.3 Level of soil K2O

The soil K2O level indicates the potential of a soil to supply K to a crop. The soil K index in N-Western Germany is ranked as 'very low'(< 2), 'low' (3 – 5), 'medium' (6 –12), 'high' (13 – 19), and 'very high' (> 20) mg per 100 g soil at depth of 0 –30 cm (Landwirtschaftskammer Nordrhein-Westfalen, 2011). The status of soil K was changed from the low to the `high` index with integration of mineral NPK fertilizer plus FYM, mineral PK fertilizer pus FYM, and application of mineral PK fertilizer without FYM (Table 7). This positive transformation of soil K did not result the highest crop yield because nutrient supply was unbalanced. Integration of mineral NP, NPKMg, and NK fertilizers with FYM ; the application of mineral fertilizers without FYM; and organic fertilizer (FYM) increased status of soil K from low to the `medium` index (Table 7).

The status of soil K was depleted from low to the ` very low` index by application of mineral N fertilizer without FYM (Table 7). Depletion of soil K content is the result of continuous K removal in crop yield without any replacement or with insufficient replacement. Integration of mineral NP fertilizer with FYM and balanced mineral fertilizer application increased soil K content in addition to maximization of crop yield, high nutrient use efficiency, and improvement of soil fertility. However application of FYM alone and unbalanced mineral fertilizer application did not result the highest crop yield and nutrient use efficiency. In general crop yield and nutrient use efficiency were reduced with application of FYM without mineral fertilizer (Figures 1, 2, & 3) and unbalanced mineral fertilizer application

(Figure 4) due to poor practices of nutrient management. Nutrient has to be effectively available to support the highest crop growth in order to maximize crop yield per area. Therefore nutrient should be efficiently managed to address the nutrient demand of crop effectively.

Treatments	C total in different years				Relative to initial	
	1958 (Initial)		2008 (Final)		2008 (Final)	
	%	kg ha $^{-1}$	%	kg ha $^{-1}$		kg ha $^{-1}$
FYM	1	42000	0.98	41160	- 2%	-840
PK	1	42000	0.96	40320	- 4%	-1680
N+PK	1	42000	0.99	41580	- 1%	- 420
N+PK+Mg	1	42000	1.01	42420	+ 1%	+420
N	1	42000	1.02	42840	+ 2%	+840
FYM +N	1	42000	1.04	43680	+ 4%	+1680
FYM +PK	1	42000	1.06	44520	+ 6%	+2520
FYM +NPKMg	1	42000	1.07	44940	+ 7%	+2940
FYM +NPK	1	42000	1.11	46620	+ 11%	+4620
FYM+NK	1	42000	1.11	46620	+ 11%	+4620
FYM+NP	1	42000	1.14	47880	+ 14%	+5880

Table 6. Soil C total at 0 to 30 cm depth.

Treatments	Milligrams of P2O5 per 100 gram soil		P index	Milligrams of K2O per 100 gram soil		K index
	1958	2008	2008	1958	2008	2008
FYM	12	20	Medium	5	7	Medium
N	12	7	Low	5	2	Very low
FYM+N	12	16	Medium	5	4	Low
N+PK	12	19	Medium	5	10	Medium
FYM+NK	12	21	High	5	12	Medium
PK	12	23	High	5	13	High
N+PK+Mg	12	23	High	5	11	Medium
FYM+NP	12	29	High	5	7	Medium
FYM+NPK	12	29	High	5	13	High
FYM+NPKMg	12	31	High	5	12	Medium
FYM+PK	12	33	High	5	15	High

Table 7. Soil P and K indexes at 0 to 30 cm depth in different years.

4. Discussion

Sources of plant nutrients are mainly mineral or organic origin. The organic source includes crop residues, animal manure, nitrogen fixation, green manure, and organic wastes. The organic materials need to get decomposed and available at a right amount, ratio, and time to effectively support growth and development of crop. Response of crop growth to organic source of nutrient depends on management and environmental conditions affecting decomposition rate of organic materials. Therefore management of organic materials is an important component of both organic and integrated plant nutrient managements. The management is mainly related to source of organic materials and , rate, method, and time of application.

Recycling of organic materials at farm level does often not fully compensate nutrient removal by crop yield, because agriculture is not a closed system. Development of export of agricultural raw materials into the world markets has enormously increased the distance nutrient travelled from fields and in the vast majority of current farms a return flow of nutrients in waste products is no longer feasible and the nutrient cycle has thus become a nutrient flow process based on mining, with substantial on-site losses in each cycle and accumulation in urban areas (Noordwijk, 1999). Hence cost of transportation limits the use of organic fertilizer over a long distance. It is also difficult to predict the availability of nutrients and to apply the right quantity and ratio of nutrients from organic fertilizer to meet nutritional requirement of the crop at the right time. Therefore locally available organic fertilizer need to be supplemented by mineral fertilizer to replace nutrient loss in a long distance of export and to minimize management difficulties in order to sustain productivity of crop production and to restore soil fertility.

4.1 Effect of nutrient management on crop yield

It is desirable to use both mineral and organic sources of plant nutrients in an integrated principle (Emeritus and Roy, 1993). Integration of mineral with organic fertilizer improves availability and corrects the balance of nutrient to achieve healthy growth and development of crop. It increased potato tuber and cereal grain yields, because nutrient availability is improved. Combination of FYM with mineral NK fertilizers increased potato yield by 45% in comparison to application of FYM alone (Figures 1). Maize grain yield was similarly increased by 52% with integration of mineral N, P, and K fertilizers with cattle manure (Abunyewa, 2007). Also application of mineral N in mixture with FYM at N supply of 50% urea and 50% FYM increased wheat grain yield by 66% in comparison to application of FYM alone at the same rate of mineral N fertilizer (Zahir and Mian, 2006). The highest potato and cereal yields with the application of FYM plus mineral NK fertilizer and FYM plus mineral NP fertilizer, respectively confirm the economic benefit of the IPNM (Figures 1, 2, and 3).

The balanced mineral fertilizer application as the BPNM resulted a higher crop yield than with FYM alone (the OPNM) and an unbalanced mineral fertilizer application (Figure 4). Potato yield in the treatment of FYM alone was 15% lower than the potato yield of the treatment with balanced mineral fertilizer application , even though quantities of N, P, K, and Mg applied as FYM was higher than the N, P, K, and Mg applied as mineral fertilizer during potato cultivation (Figure 4 and Tables 4 & 2). Application of organic fertilizer alone does not fully satisfy nutritional requirement of crop because it is relatively difficult to balance nutrient availability to maximize crop growth and yield per area. Application of FYM alone decreased potato yield by 31% in comparison to integration of mineral NK fertilizer with FYM and it also reduced winter rye and oat yield by 56% in comparison to application of mineral NP fertilizer plus FYM (Figures 1, 2, and 3). In general with the best nutrient management practices, the IPNM and the BPNM, the highest crop yield per area were achieved in comparison to inferior management practices like the OPNM and the unbalanced mineral fertilizer application.

Maximization of crop production per area is the basis to achieve sufficient and affordable food to effectively meet the demand of a growing world population. Promotion of optimal and efficient plant nutrition is required on a large scale to achieve the 700 million tonnes of additional cereals that will be required by 2020. About 80% of the additional demand will have to come from already cultivated areas (Roy et al. 2006). Harvesting a maximum yield per area is the primary criteria to secure supply of food considering the limited potential to extend the crop land area globally (Bruinsma, 2003). Integration of mineral with organic fertilizer is one of the effective practices of plant nutrient management to increase crop yield per area. Therefore the highest yields of crop with FYM+NK (potato) and FYM+NP (cereal) treatments also supports the social benefit of the IPNM (Figures 1, 2, and 3).

4.2 Effect of nutrient management on nutrient use efficiency

Nutrient in organic materials should be used efficiently in order to increase crop yield per area and to reduce nutrient loss. Integration of mineral fertilizer with FYM increased nutrient use efficiency (NUE) of crops. However with application of organic fertilizer (FYM) alone the NFUE, the PFUE, and the KFUE of crops were reduced by 27% , 63%, and 57%, respectively in comparison to the highest nutrient use efficiency at the integration of mineral fertilizers with FYM (Table 5). The highest NFUE and KFUE were achieved with the integration of mineral NP fertilizer with FYM and the highest PFUE was achieved with the integration of mineral NK fertilizer with FYM (Table 5). Integration of NP with FYM increased NFUE and KFUE and application of FYM plus mineral NK fertilizer increased PFUE of crops; because application of one nutrient increases use efficiency of other nutrient through synergistic effect, i.e. the total essential functions of two or more nutrients is higher than the sum of the essential functions of a single nutrient.

The NFUE and the PFUE of crops were decreased by 37% and 16%, respectively with application of FYM alone in comparison to the balanced mineral fertilizer application (Figure 5). This indicates that nutrient in the FYM is not sufficiently available for uptake by crop at the right growth stages. Balanced mineral fertilizer application (the N+P+K+Mg treatment) resulted the highest yield of crops with the highest nutrient use efficiency: thereby, it balances economic, social, and environmental conditions for sustainability of crop production (Jate, 2010). Loss of N and P to the environment is reduced through improvement of NFUE and PFUE of crops by integration of NP and NK mineral fertilizers with FYM and balanced mineral fertilizer application. Therefore negative effects of N and P loss on environment is minimized with the approaches of the IPNM and the BPNM as the best practices of plant nutrient management.

4.3 Effect of nutrient management on soil fertility

Improvement of soil fertility is one of the basic criterions to maximize crop yield and to minimize nutrient loss per area. Integration of mineral with organic fertilizer increases soil fertility through improvement of physical, biological and chemical properties of soil. Improvement of soil organic matter improves soil physical properties and it increases nutrient availability that these improvements should ultimately lead to increase of crop growth and yield (Onemli, 2004). Application of FYM plus mineral fertilizer improved soil fertility through improvement of organic matter and nutrient content of the soil (Tables 6 and 7). Fertilizer application significantly increased the concentrations of N, P, K and organic carbon in the plough layer of soil (Ishaq et al. 2002).

Integration of mineral N and P fertilizers with FYM achieved 16% more organic matter (carbon) content of the soil in comparison to application of FYM alone (Table 6). It resulted the highest crop yield per area with application of FYM plus mineral NP fertilizer (Figures 2 and 3). Similarly the integration of compound NPK (20:10:10) fertilizer at 150 kg ha^{-1} with FYM (cocoa pod ash) at 10 t ha^{-1} increased maize grain yield and soil carbon content by 24% and 16%, respectively in comparison to FYM without mineral fertilizer (Ayeni, 2010). Accumulation of soil organic matter content improves growth condition for crop production through improvement of soil fertility and it also reduces CO_2 emission through sequestration of carbon in the root biomass. Therefore both soil fertility and environmental benefits are achieved with the practice of IPNM.

Fertilizer application increases crop yield per area through direct improvement of nutrient concentration in the soil. Integration of mineral NP and NK fertilizers with FYM and balanced mineral fertilizer application sustained high soil P (Table 7) and medium soil K (Table 8) status in addition to improvement of crop yield, nutrient use efficiency, and soil organic matter. Neither organic fertilizer alone nor unbalanced mineral fertilizer application ensures sustainability of crop production. Integration of mineral with organic fertilizer and balanced mineral fertilizer application sustain crop production through improvement of soil fertility and nutrient use efficiency. Therefore the IPNM and the BPNM are the best practices of plant nutrient management to increase crop production per area, to restore soil fertility, and to minimize negative effect of nutrient loss on environment.

5. Conclusion

Availability of sufficient quantity and effective form of nutrient just on a time at a right ratio and even distribution at root zone and canopy surface are the major parameters of nutrient management responsible to optimize nutrient uptake and crop yield. Application of organic fertilizer (FYM) plus mineral fertilizers as integrated plant nutrient management (IPNM) increases crop production per unit area through improvement of nutrient availability. It also improves nutrient use efficiency and soil fertility. The approach of IPNM combines economic, social, environmental, and soil fertility benefits of the best practice of nutrient management. These benefits are the basic criteria to sustain high crop yield per area in order to secure physical availability and socio-economic accessibility of food at a family, a local, a country, a regional, and global levels.

The IPNM is one of the best practices of plant nutrient management that determines crop production potential of a soil in addition to its positive effect on nutrient use efficiency to minimize negative impacts of agriculture on quality of environment. It contributes to environment protection through reduction of N and P losses and sequestration of carbon in the soil organic matter. It reduces imbalances of nutrients; it limits uncertainty of nutrient availability; it minimizes nutrient loss; it enhances soil organic matter content; and it avoids degradation of soil fertility. These major positive effects are very important to maximize crop yield per area, to improve nutrient use efficiency, and to ensure sustainability of soil fertility.

The highest crop yield with the approach of the IPNM, in comparison to application of organic fertilizer alone (the OPNM), is the result of improvement of nutrient availability, balance, and uptake. The practice of the IPNM can balance rate and ratio of nutrient availability at the right growth stages of crop to increase yield per area with environmental responsibility. Increase of crop production per area is needed to sustain physical availability and socio-economic ability to access food for humans and feed for animal consumptions. Nutrients of organic sources are taken up by plant roots after they are broken down (mineralized) into ionic forms. For the crop uptake there is no ionic difference between N, P, K, Ca, Mg, S, etc available from mineral and organic fertilizers. Therefore integration of mineral with organic fertilizer (the IPNM) is securer than the organic fertilizer alone (the OPNM): because more crop yield and less nutrient loss per hectare has been achieved with the IPNM compared to the OPNM.

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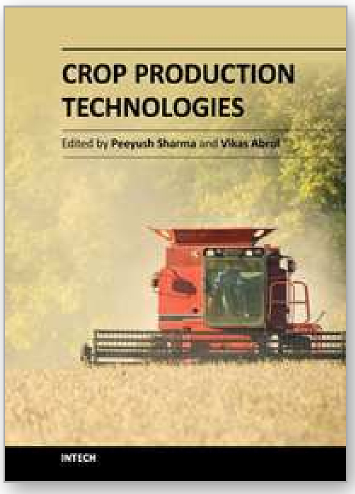

Crop Production Technologies

Edited by Dr. Peeyush Sharma

ISBN 978-953-307-787-1
Hard cover, 276 pages
Publisher InTech
Published online 05, January, 2012
Published in print edition January, 2012

Crop production depends on the successful implementation of the soil, water, and nutrient management technologies. Food production by the year 2020 needs to be increased by 50 percent more than the present levels to satisfy the needs of around 8 billion people. Much of the increase would have to come from intensification of agricultural production. Importance of wise usage of water, nutrient management, and tillage in the agricultural sector for sustaining agricultural growth and slowing down environmental degradation calls for urgent attention of researchers, planners, and policy makers. Crop models enable researchers to promptly speculate on the long-term consequences of changes in agricultural practices. In addition, cropping systems, under different conditions, are making it possible to identify the adaptations required to respond to changes. This book adopts an interdisciplinary approach and contributes to this new vision. Leading authors analyze topics related to crop production technologies. The efforts have been made to keep the language as simple as possible, keeping in mind the readers of different language origins. The emphasis has been on general descriptions and principles of each topic, technical details, original research work, and modeling aspects. However, the comprehensive journal references in each area should enable the reader to pursue further studies of special interest. The subject has been presented through fifteen chapters to clearly specify different topics for convenience of the readers.

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